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The outdoor thermal benchmarks in Melbourne urban climate

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Abstract

Outdoor thermal comfort significantly influences the users' experience in urban places; affecting their extent of usage. The paper aims to identify the outdoor thermal benchmarks for the temperate oceanic (Cfb) climate zones in Australia. It examines the perception of thermal comfort in two urban places in Melbourne city. Field measurements were conducted during summer and winter seasons along with 2123 valid questionnaires and observations in both contexts. Micrometeorological parameters were measured and used to calculate the mean radiant temperature and the physiological equivalent temperature (PET). The questionnaire provided information regarding the thermal sensations and preferences of the users using ASHRAE seven-point and McIntyre scales respectively. The quantitative analysis is used to calculate the range of outdoor thermal comfort in Melbourne. This was ranged between 20 °C and 25 °C PET. Additionally, the neutral and preferred temperature were found to be 20.4 °C and 19.2 °C respectively. Variations in different benchmarks were observed with different seasons and types of urban places. The results endorse the significant impact of thermal adaptation factors on the users' comfort levels and acceptability for micrometeorological environments. The findings also identify the different thermal benchmarks that help urban designers creating comfortable outdoor places within the oceanic temperate climatic zones.

Keywords

Outdoor thermal comfort; Temperate oceanic climatic zone (Cfb); Thermal comfort ranges; Thermal adaptation; Physiological equivalent temperature.

1 Introduction

Designing thermally comfortable outdoor places has proven to be a significant factor for the extent of their success; influencing the users' attendance and positive behaviour (Aljawabra & Nikolopoulou, 2010; Eliassona, Knez, Westerbergb, Thorssona, & Lindberga, 2007). Previous research showed how micrometeorological conditions influence the participation of users in outdoor places during different seasons. In USA and Canada, the participation of users in the outdoor places represented an average of 10% and 3% during summer and winter respectively (Leech, Burnett, Nelson, & Aaron, 2000). Being challenged by several variables, outdoor thermal comfort (OTC) studies have been characterised by its complexity. Many attempts took place to identify the different factors affecting OTC sensation (Chen & Ng, 2012). Micrometeorological parameters are the most apparent variables responsible for thermal sensation in outdoor places. However, the expansive variation between objective micrometeorological measurements and subjective human thermal sensation votes suggested significant effects of physical, physiological and psychological adaptation (Nikolopoulou & Steemers, 2003). Besides these factors, outdoor places have a lower control over micrometeorological parameters, which adds to this complexity. Understanding the OTC ranges of users is, therefore, a valuable tool for urban designers that enriches the design possibilities by creating comfortable outdoor public places, and accordingly, increase their success rate and contribute to the sustainability of cities (Cheung & Jim, 2017).

Previous research attempted to identify OTC ranges in places with different geographical and micrometeorological characteristics including parks (Kántor & Unger, 2010; Lam, Loughnan, &

Tapper, 2018; Mahmoud, 2011; S Thorsson, Lindqvist, & Lindqvist, 2004), urban squares (da Silveira Hirashima, de Assis, & Nikolopoulou, 2016), streets (Holst & Mayer, 2011; Lee, Holst, & Mayer, 2013; Mayer, Holst, Dostal, Imbery, & Schindler, 2008) and university campuses (Salata, Golasi, de Lieto Vollaro, & de Lieto Vollaro, 2016; Shooshtarian & Ridley, 2016; Xi, Li, Mochida, & Meng, 2012). As Chen and Ng (2012) identified modelling and empirical methods are the two main approaches used in assessing OTC. The empirical method prevails due to relying on detailed analysis for both objective micrometeorological parameters affecting thermal comfort and subjective assessments of users. Research on subjective thermal comfort perception generally employs questionnaires as the main data collection tool. The number of respondents to the questionnaires in previous OTC studies varied widely from eight to 7851 (Liu, Zhang, & Deng, 2016; Salata et al., 2016); as does the duration of field surveys from one day to two years. However, as Salata et al. stated (2016), summer and winter were the most frequently investigated seasons. Different scales were used for respondents to specify their thermal sensation votes. ASHRAE 7 points scale (cold, cool, slightly cool, neutral, slightly warm, warm, hot) is the most commonly employed (Lin, 2009; Lin, de Dear, & Hwang, 2011; Ng & Cheng, 2012; Pantavou, Theoharatos, Santamouris, & Asimakopoulos, 2013; Salata et al., 2016; Yang, Wong, & Jusuf, 2013; Yang, Wong, & Zhang, 2013). However, few studies used the 5 points scale (very cold, cool, neutral, warm, very hot) (Nikolopoulou, Baker, & Steemers, 2001) and the 9 points scale (very cold, cold, cool, slightly cool, neutral, slightly warm, warm, hot, very hot) (Kántor, Égerházi, & Unger, 2012; Liu et al., 2016; Yahia & Johansson, 2013). To identify thermal preferences, the McIntyre (1980) scale ranging from cooler (-1), no change (0) to warmer (+1) preferences is used (Cheng, Ng, Chan, & Givoni, 2012; Lin, 2009; Lin et al., 2011; Salata et al., 2016; Yang, Wong, & Jusuf, 2013). Different rational thermal comfort models were employed in outdoor settings. Chen and Ng (2012) explained that to have a significant effect on planning practice, these models are to be supported by both human-biometeorological and physiological information. The indexes were originally dependant on the energy fluxes between the human body and the environment. The Predicted Mean Vote Index (PMV), Effective Temperature (ET in °C), and Standard Effective Temperature (SET* in °C) (Fanger, 1982; Gagge, Fobelets, & Berglund, 1986); are examples of indexes originally developed for indoor thermal comfort studies and were later adapted to be applied in outdoor settings (Cheng et al., 2012; Nikolopoulou et al., 2001; S Thorsson et al., 2004). The Outdoor Standard Effective Temperature (OUT_SET* in °C) (Spagnolo & de-Dear, 2003) and the Physiological Equivalent Temperature (PET in °C) (Mayer & Höppe, 1987) are thermo-physiological assessment variables that were purposely designed for outdoor settings. PET is the most predominant thermal comfort index used in the OTC studies (da Silveira Hirashima et al., 2016; Elnabawi, Hamza, & Dudek, 2016; Holst & Mayer, 2011; Kántor, Égerházi, et al., 2012; Lee et al., 2013; Lee & Mayer, 2018; Lee, Mayer, & Chen, 2016; Lee, Mayer, & Schindler, 2014; Lin & Matzarakis, 2008; Lin, 2009; Liu et al., 2016; Mayer et al., 2008; Ng & Cheng, 2012; Salata et al., 2016; Yang, Wong, & Zhang, 2013).

The most commonly used benchmarks to identify OTC are neutral PET (NPET), preferred PET (PPET), thermal acceptability range (TAR), and neutral PET range (NPETR). As observed by Cheung and Jim (2017), different methods are used to define and calculate those benchmarks. NPET is widely expressed as the temperature arising from neutral thermal sensation (Fanger, 1982). The linear regression, quadratic regression and the probit analysis are three different methods used in calculating NPET. As determined by Kántor, Kovács, and Takács (2016), these different techniques led to significant variations in the NPET values. The linear regression between mean thermal sensation votes (MTSV) and PET is the most widely used method in calculating NPET in similar studies (Chen, Wen, Zhang, & Xiang, 2015; Cohen, Potchter, & Matzarakis, 2013; Elnabawi et al., 2016; Kántor, Égerházi, et al., 2012; Lin & Matzarakis, 2008; Lin, 2009; Mahmoud, 2011; Salata et al., 2016; Yang, Wong, & Zhang, 2013). Although this method was criticized by assuming that thermal sensation votes are continuous instead of ordinal data (Cheung & Jim, 2017), this impact was found to be insignificant (Salata et al., 2016). Few studies used the same method having the linear regression using different other thermal comfort indexes (Pantavou et al., 2013; Yang, Wong, & Jusuf, 2013; Zhao, Zhou, Li, He, & Chen, 2016). PPET is the ultimate temperature in which the probabilities of users' preferences towards having warmer and cooler changes are equivalent. To calculate PPET, a probit regression analysis for both warmer and cooler preferences is modelled and the intersection of both corresponds to the preferred temperature (Lin, 2009; Lin et al., 2011; Salata et al., 2016; Yang, Wong, & Jusuf, 2013; Yang, Wong, & Zhang, 2013; Zhao et al., 2016). TAR is the limit determining the temperature accepted by 80 or 90% of the respondents (ASHRAE, 2004). This range is generated from a quadratic regression between the thermal acceptability of the respondents and the temperature. Yang, Wong, and Jusuf (2013) calculated this range based on the assumption that 80% acceptability rate corresponds to the value of ±0.85 MTSV in the linear regression between the binned MTSV and the temperature as per ISO-7730 (2005). NPETR corresponds to the values ranging from -0.5 to +0.5 MTSV in the NPET linear regression (Chen et al., 2015; Kántor et al., 2016; Lai, Guo, Hou, Lin, & Chen, 2014; Liu et al., 2016; Salata et al., 2016). Different benchmarks obtained in similar OTC studies are summarised in Table 1, showing that the NPET is the most commonly used and the NPETR values are the least reported.

This paper aims to identify the different outdoor thermal comfort benchmarks for Melbourne city representing the temperate Oceanic climatic zone in Australia, adopting the most commonly used methods in OTC studies, to help ultimately urban designers and urban planners in designing comfortable outdoor public places.

Place	Koppen classification	Season	Urban place	Micrometeorological measurements	responses	Scale	Index	N PET	P PET	TA R	NPET R
Singapore, Singapore (Yang, Wong, & Zhang, 2013)	Tropical rainforest (Af)	August to May	13 urban spaces (parks, squares, streets, campuses and quay)	Air temperature (Ta), globe temperature (Tg), relative humidity (RH), wind speed (V), Vapour pressure (VP),& global radiation (G)	2020 valid	ASHRAE 7 pts	PET	√	√	√	
Singapore, Singapore (Yang, Wong, & Jusuf, 2013)	Af	Aug. to May	13 urban spaces	Ta, Tg , RH, V & G	2036 valid	ASHRAE 7 pts	OT	√	√	√	
Belo Horizonte, Brazil (da Silveira Hirashima et al., 2016)	Tropical wet (Aw)	Summer & winter	Urban squares	Ta, Tg, RH, & V	1693	Other 7 pts	PET	√	√	√	
Damascus, Syria (Yahia & Johansson, 2013)	Semi-arid cool (Bsk)	Summer & winter	2 types of residential areas and parks	Ta, Tg , RH, V & wind direction (WD)	920	9 pts	PET OUTSET	√	-	√	-
Cairo, Egypt (Elnabawi et al., 2016)	Hot arid (Bwh)	Summer & winter	Street	Ta, Tg, RH, V & solar radiation (SR)	320	ASHRAE 7 pts	PET	√	√	√	-
Shanghai, China (Chen et al., 2015)	Humid Sub-tropical (Cfa)	Autumn & winter	Urban park	Ta, Tg, RH, V & G	596	ASHRAE 7 pts	PET	-	-	√	√
Guangzhou, China (Li, Zhang, & Zhao, 2016)	Cfa	Summer, winter & spring	4 residential communities (resting areas)	Ta, Tg , RH, V & G	1005	9 pts	PET	√	√	√	-
Guangzhou, China (Zhao et al., 2016)	Cfa	Aug. - mid-Oct.	University	Ta, Tg, RH, V & G	1582	ASHRAE 7 pts	SET*	√	√	√	
Changsha, China (Liu et al., 2016)	Cfa	All year	6 typical public spaces	Ta, Tg, RH, & V	7851 valid	9 pts	PET	√	-	-	√
Changsha, China (Yang, Wong, & Zhang, 2013)	Cfa	June to Aug.	17 urban spaces (parks, squares, streets & campuses)	Ta, Tg, RH, V, VP & G	2052	ASHRAE 7 pts	PET	√	√	√	-
Sydney, Australia (Spagnolo & de-Dear, 2003)	Cfa	Summer & winter	Outdoor and semi outdoor places	Ta, RH, V, short & long wave radiation fluxes (K and L)	1018	ASHRAE 7 pts	OT, ET*, OUTSET*, PET	√	√	-	-
Sun moon lake, Taiwan (Lin & Matzarakis, 2008)	Cfa	All year	Touristic area	Ta, Tg, RH, V & G	1644	ASHRAE 7 pts	PET	√	-	√	-
Szeged, Hungary (Kántor, Égerházi, et al., 2012;	Temperate Warm (Cfb)	Autumn & Spring	2 urban squares	Ta, RH, V, K and L	967	9 pts	PET	√	-	√	√

Kántor, Unger, & Gulyás, 2012)											
Szeged, Hungary (Kántor et al., 2016)	Cfb	Spring, summer & autumn	6 recreational areas	Ta, RH, V, K and L	5805 valid	9 pts	PET	√	√		√
Melbourne, Australia (Shooshtarian & Rajagopalan, 2017; Shooshtarian & Ridley, 2017)	Cfb	Spring, summer & autumn	University campus	Ta, Tg), RH, V and G	1023 valid	ASHRAE 7 pts	PET	√	√	√	-
Athens, Greece (Pantavou et al., 2013)	Hot dry summer (Csa)	All year	3 places (square, street, & region)	Ta, Tg), RH, V, SR and G	1706	ASHRAE 7 pts	UTCI	√	-	√	-
Tel Aviv, (Cohen et al., 2013)	Csa	Summer & winter	3 places (parks, street & square)	Ta, RH, V, WD and G	1731	9 pts	PET	√	-	√	-
Rome, Italy (Salata et al., 2016)	Csa	Feb. to Jan.	Sapienza University campus	Ta, Tg , RH, V and G	941 valid	ASHRAE 7 pts	PET	√	√		√
Taichung, Taiwan (Lin, 2009)	Dry-winter humid sub-tropical (Cwa)	Apr. to Feb. (hot & cool)	Public square	Ta, Tg, RH, V and G	505	ASHRAE 7 pts	PET	√	√	√	
Tianjin, China (Lai et al., 2014)	Hot summer continental (Dwa)	March to Jan.	Park	Ta, Tg, RH, V and G	1585	ASHRAE 7 pts	PMV, PET, UTCI	-	-	-	√

Table 1 Different methods and results from similar OTC studies

2 Study area

Melbourne city is situated between latitude 37°49′′ south and longitude 144°58 ′′ east of Australia having a total area of 9990.5 km^2. The climatic conditions in Melbourne city are within the temperate climate group (cfb) according to the widely used Köppen- Geiger climatic classification, having uniform precipitation distribution and warm summers. The summary of major climate statistics recorded at Melbourne Regional Office (latitude: 37.81° S, longitude 144.97° E, elevation 31m) from the year 1855 to 2015 shows that the mean air temperature lies between minimum and maximum of 13°C and 26°C during summer and between 6°C and 15°C during winter as shown in Fig. 1. The mean rainfall recorded during the same period ranged between 47 mm and 66 mm during January and October respectively. The mean daily sunshine varied between 4 h to 9 h in June and January respectively. The relative humidity at 9:00 am and 3:00 pm were also noted to have a minimum of 62% (October and December), and 47% (December and January) and a maximum of 80% (June) and 63% (June) respectively. The wind speed in the same conditions was documented with a value of minimum 2.4 (April) and 3.5 m/s (May) and a maximum of 3.5 (October) and 4.4 m/s (September) for both 9 am and 3 pm respectively (BOM, 2017). According to the Beaufort comfort scale for wind speed, these values range from the light breeze to gentle breeze, which is relatively comfortable (Burberry, 1997).

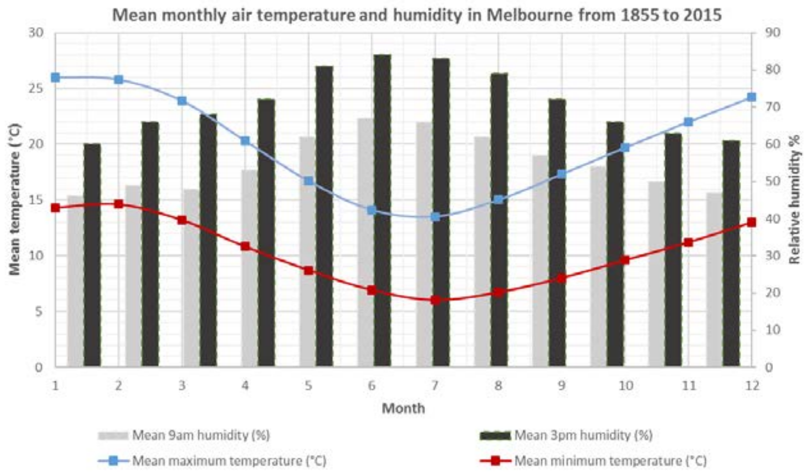


Figure 1 Mean monthly air temperature and humidity in Melbourne (1855_ 2015)
Source: The authors based on (BOM, 2017)

The study was employed in two different types of urban places; the Federation square and Deakin University's Burwood campus; having different functions, activities, urban characteristics, as well as the frequency of visits. The distance between the two study areas is 14.5 km. As per Gehl (2011) classification to urban places, Federation square represents places where optional and social activities take place, which require a higher quality and accordingly better climatic comfort levels. Conversely, Burwood campus exemplifies places where necessary activities are more dominant where less quality could be tolerated.

2.1 Federation square

Federation square is a main attraction in the Central Business District (CBD) of Melbourne. A total area of 3.2 ha situated in the intersection of two key linear paths having the ability to accommodate 15000 people at one time. The square is surrounded by key buildings including the National Gallery of Victoria, cafes and restaurants providing different activities for their visitors. Having this unique location facilitates its role as a place for people to gather, a landmark for tourists to visit as well as a spot for public activities events that are frequently organised. The flooring in Federation square is mainly paved with sandstone cobblestones. Concrete and bluestone also cover few parts of the square and green infrastructure is very limited (Fig. 2a).

2.2 Deakin Burwood campus

Burwood campus is the largest campus for Deakin University accommodating around 20800 undergraduate and postgraduate students. It is located around 15 km from Melbourne CBD. Facilities in the campus include art collection and galleries, bookshop, childcare, library, sports centre, lecture theatres, computer labs, medical centre and counselling services, multi-faith prayer rooms as well as on-campus accommodation. This field study took place in the main gathering area for students in the central courtyard located between the library, learning spaces, food outlet and student life department from the north, south, east and west sides respectively. The campus is mainly paved with concrete and has numerous green areas (Fig. 2b).

(a) (b)

Figure 2 Studied urban places (a) Federation square (b) Burwood campus Source: (Melbourne-for-the-visitor, 2017; Rushwright-associates, 2017)

3 Material and methods

This empirical study applied both objective field measurements and subjective assessments of human perceptions (Fig. 3). Field measurements describing the micrometeorological conditions for studied places were employed simultaneously with structured questionnaires and observations for examining human thermal sensation. As recommended by Ng and Cheng (2012), meteorological measurements were distanced within a maximum of three meters from questionnaires' respondents. The results of both objective and subjective examination were correlated to identify the outdoor thermal requirements of users. The data were collected during summer between January and February 2013 and 2014 and during winter from July to August 2013 and 2014 from 9:00 am to 5:00 pm to examine different micrometeorological conditions. In Federation square, both weekdays and weekends were included to have a comprehensive assessment for the different days. However, in Burwood campus, due to its functional character, only weekdays during teaching periods were considered. Rainy days were excluded from both case studies.

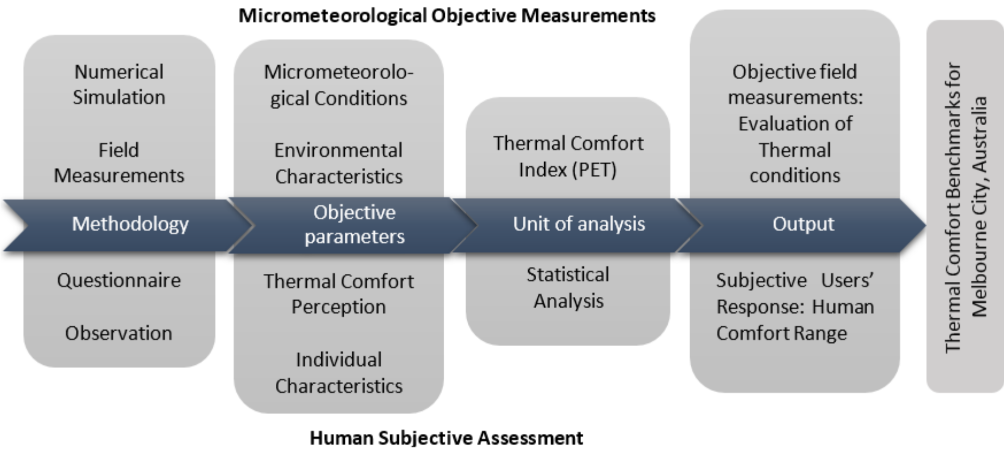


Figure 3 Selected methods chart

3.1 Microclimatic objective measurements:

3.1.1 Field measurements

As per previous studies, the recorded micrometeorological parameters in this study are the ambient air temperature (Ta in °C), relative humidity (RH in %), wind speed (V in m/s), solar radiation (Ra in w/s2) and globe temperature (Tg in °C) used in calculating the mean radiant temperature (T_{mrt}) (Chen et al., 2015; Cheng et al., 2012; Krüger, Drach, Emmanuel, & Corbella, 2013; Lai et al., 2014; Li et al., 2016; Pantavou et al., 2013; Salata et al., 2016). Additional micrometeorological parameters were obtained from the nearby Melbourne (Olympic Park) weather station (such as cloud cover and water vapour pressure) . The weather station is 8 m above sea level and located 2 and 10.4 km away from Federation square and Burwood campus respectively.

The Mobile Architecture and Built Environment Laboratory (Mabel) thermal comfort carts were used in monitoring micrometeorological parameters for their high accuracy and mobility during the field visit. The comfort carts are designed to assess thermal environments according to the procedures and protocols prescribed in ASHRAE's thermal comfort standard- ASHRAE 55-92R and ISO 7726 Ergonomics of the thermal environment - Instruments for measuring physical quantities (ISO, 2002). Each cart measures the micrometeorological parameters simultaneously at four heights. The LO, MID, HI and HEAD heights measure at 0.1, 0.6, 1.1 and 1.7 m above the floor respectively. The LO, MID, and HI heights correspond to the ankles, waist, and head of a seated person respectively; and the HEAD height corresponds to the head of a standing person. The (Ta) and (Tg) are monitored through two temperature probes at the LO, MID and HI heights. One thermocouple exists at the HEAD level for (Ta) measurements. The accuracy of the three OMEGA 44032 linear thermistors that recorded both (Ta) and (Tg) was 0.1 °C. A HyCal integrated humidity sensor (IH-3605-B) were used to record relative humidity (RH) with 2% accuracy at MID height. A polystyrene circular white disc protected both temperature and humidity sensors from direct sun exposure. Digital TSI anemometers with omnidirectional hot wire type of anemometer probes were monitoring (V) at the different heights. The anemometers were calibrated to meet the specified measurement accuracy of 3 % of reading within the response time of 0.2 s. The heart of the system, Campbell Scientific CR23X data logger, is a fully programmable data acquisition system that can run MABEL carts in different operational modes enabling quick and efficient performance of cross-sectional thermal comfort research (Fig. 4).

Another weather station was installed measuring Ta; V and RH for cross-checking purposes. The portable station was also used for the solar radiation. The measuring device used was a Kipp and Zonen pyranometer for global irradiance (Boland, Ridley, & Brown, 2008). The design of the mobile meteorological station is consistent with other meteorological devices used in past studies (Holst & Mayer, 2011; Lee et al., 2013; Lee et al., 2014; Helmut Mayer et al., 2008; Ng & Cheng, 2012; Nikolopoulou & Steemers, 2003; Spagnolo & de-Dear, 2003). The devices were all tested and calibrated before the survey and their timing systems were synchronized with Melbourne standard time. During the field measurements, the devices were allowed 10 -15 minutes response time before the actual recording. The comfort carts were placed in both open sky and shaded area, and were programmed to record all measured data at 1 and 15 min intervals automatically.

Figure 4 MABEL comfort cart

3.1.2 Thermal comfort index

Each questionnaire was associated with its corresponding micrometeorological measurements taking into consideration its location and time. To assess thermal comfort levels, respondents' thermal perception, preferences and acceptances are linked to the thermal comfort index calculated from these micrometeorological parameters. As stated previously, PET is the most commonly used and recommended index in OTC studies. It is the heat balance model of human body based on Munich Energy-balance Model for Individuals (MEMI), and defined as the air temperature in a typical indoor setting at which the heat balance of the human body is maintained by skin temperature, core temperature, and sweat rate equal to those under the conditions to be assessed (Höppe, 1999). PET is expressed in Celsius and assumes constant values of 0.9 CLO for clothing and 80 W for metabolic rate. It is calculated in this study through Rayman software, version 1.2 (Lee & Mayer, 2016; Matzarakis, Rutz, & Mayer, 2007) using Ta (°C), RH (%), V (m/s), T_{mrt} (°C), and cloud cover (octas) in addition to respondents' age and gender characteristics as input data (Makaremi, Salleh, Jaafar, & GhaffarianHoseini, 2012).

3.1.3 The mean radiant temperature (T_{mrt})

Mean radiant temperature is defined as the 'uniform temperature of an imaginary enclosure in which the radiant heat transfer from the human body equals the radiant heat transfer in the actual non-uniform enclosure' (ASHRAE, 2001). The importance of T_{mrt} returns to its significant influence on the energy balance and thermal comfort of the human body (Mayer & Höppe, 1987; Spagnolo & de-Dear, 2003). T_{mrt} is a critical factor used in calculating PET index. Using Tg in calculating T_{mrt} reported a relatively small difference in accuracy when compared to other methods based on integral radiation measurements and angular factor (Thorsson, Honjo, Lindberg, Eliasson, & Lim, 2007). Following similar research (Chen et al., 2015; Cheng et al., 2012; Krüger et al., 2013; Lai et al., 2014; Li et al., 2016; Pantavou et al., 2013; Salata et al., 2016), T_{mrt} is calculated based on the conversion of globe temperature data measured by the globe thermometer consisting of a thermocouple wire held at the middle of a 38 mm diameter black table-tennis ball in the previously specified comfort carts using Eq. (1) (Thorsson, Lindberg, Eliasson, & Holmer, 2007).

$$Tmrt = \left(\frac{(Tg+273)^4 + (1.1 * 10^8 \ Va^{0.6})(Tg-Ta)}{\varepsilon D^{0.4}}\right)^{1/4} - 273 \qquad \textbf{(1)}$$

Where: D is globe diameter (m) (= 0.038 m in this study), and ε is emissivity (= 0.95 for black coloured globe).

3.2 Human subjective assessment

3.2.1 Questionnaires & observations

The randomly distributed designed questionnaire was divided into three main parts starting with the respondents' personal data including their age, gender, clothing, activities, etc. Clothing values were calculated using the checklist used by Ng and Cheng (2012). Activities were converted into metabolic rates of 1, 1.2, and 2 met for users' sitting, standing and walking respectively. Both calculations were adopted from the ASHRAE standard 55 (2004) and ISO-7730 (1994). Respondents were then required to indicate their thermal perception according to ASHRAE 7 points scale to enable reliable comparisons of results with various OTC studies using the same scale. Thermal acceptability and preferences using the McIntyre scale (cooler -1, no change 0 and warmer +1) were also recorded. Additional data including time of response, the location of respondents in the place, and sky conditions were simultaneously observed and filled with an observation sheet. Johansson, Thorsson, Emmanuel, and Krüger (2014) suggested a range of 400 to 500 respondents to be a reliable sample size for OTC studies. Using the equation developed by Cochran (2007), a minimum of 118 respondents is calculated as an acceptable sample size for this study.

4 Results

4.1 Descriptive analysis

4.1.1 Respondents

A total of 2123 users responded to the questionnaires, which fulfils the sample size required for generalisation. A balanced distribution of respondents was noted in both urban places and seasons studied. The numbers of respondents in Federation square and Burwood campus were 1021 and 1102 respectively. During summer and winter, the respondents were 1146 and 977 respectively. A variation in the pattern of usage and attendance could be noticed in Federation square in different seasons during the weekdays and the weekends. The attendance on weekends during summer was much higher than weekdays (1.8) while this percentage was almost similar during winter (1.2). This ratio suggests that the micrometeorological conditions during summer are more encouraging for users to visit outdoor public places to carry out their optional activities during weekends. The gender distribution of the sample also indicated a slightly higher attendance of female in both places. The total number of female to male is 567 to 454, and 665 to 437, in Federation square, and Burwood campus respectively. To represent accurately the thermal sensation votes of respondents, the users living in the city for less than 6 months as well as pregnant women were excluded (Salata et al., 2016).

4.1.2 Micrometeorological measurements

The frequency of measured air temperature at both urban places varied from a minimum of 17.5°C and 7.3°C and a maximum of 34.6°C and 18.4°C for summer and winter respectively. In Burwood campus and Federation square the minimum values were 19.3°C and 9.5°C and the maximum values were 28.8°C and 17°C for summer and winter respectively. According to the PET classification values for temperate climate (Matzarakis, Mayer, & Isiomon, 1999), during summer these values ranged from neutral to slightly warm at the Federation square, and from slightly cool to warm at Burwood campus. During winter, the Federation square temperature ranged from slightly cool to cool and Burwood campus temperature ranged from neutral to cold. As shown in Figure 5, Burwood campus has a wider range of air temperature during both seasons.

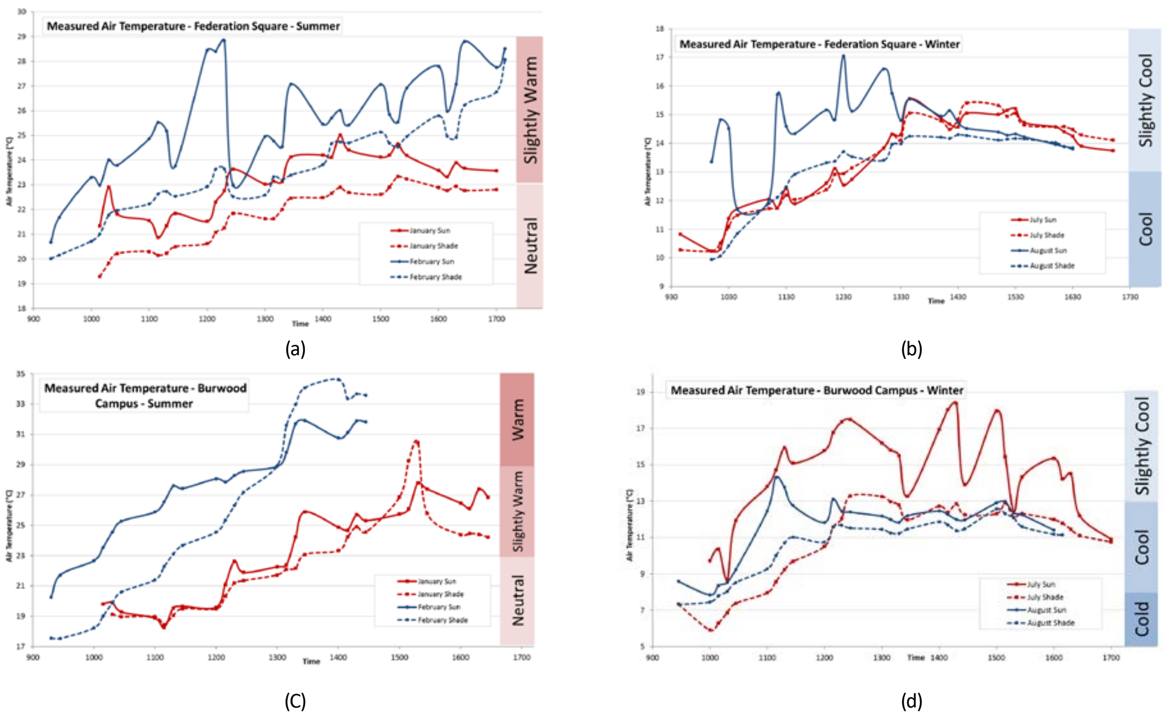


Figure 5 The frequency of measured air temperature in Federation square (a) during summer, (b) during winter; and in Burwood campus (c) during summer and (d) during winter

The distribution of V, RH, and G are detailed in Table 2. According to the Beaufort comfort scale (Burberry, 1997), V values at the Federation square and Burwood campus during both seasons varied from calm to light breeze. These values represent very light wind only felt on exposed skins. RH varied from 8.4% to 84.5% during summer and from 41.5% to 95.7% during winter. RH values at Burwood campus tended to be lower and higher than in Federation square during summer and winter respectively. G during summer and winter in both places varied from 45 to 903 W/m^2 during summer and from zero to 513 W/m^2 during winter. Both the global and the diffuse radiation values during winter were noticeably less than during summer.

Place	Season	Wind Speed (m/s)		Relative Humidity (%)		Global Radiation (w/m^2)	
		Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
Federation square	Summer	0.15	0.7	31.5%	83%	45	903
	Winter	0.36	1.47	41.5%	66.3%	0	513
Burwood campus	Summer	0.3	2	8.4%	84.5%	328	879
	Winter	0.27	1.1	47.5%	95.7%	24.1	470.4

Table 2 Distribution of wind speed, relative humidity and radiation in Federation square and Burwood campus

4.1.3 Thermal sensation votes (TSV)

The TSV identifies the thermal perception of users obtained from the ASHRAE scale in the questionnaire (Fig. 6). A percentage of 14.7% of the total respondents selected to feel thermally neutral (TSV=0). The votes inclined towards the cold (TSV<0) and warm (TSV>0) directions were 53% and 32.2% respectively. The frequency distribution of thermal sensation votes in the different seasons showed an absolute skewness of -0.412 and +0.987 during summer and winter respectively. This skewness is in line with the Micrometeorological measurements that ranged from warm (2) to cold (-3) feeling according to the temperate regions' PET classification (Matzarakis et al., 1999).

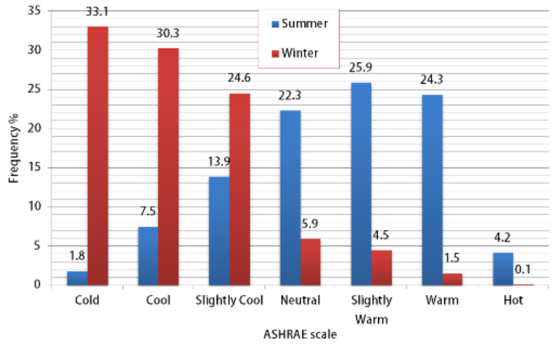


Figure 6 Distribution of thermal sensation votes during summer and winter

4.2 Thermal comfort benchmarks

4.2.1 Neutral PET (NPET)

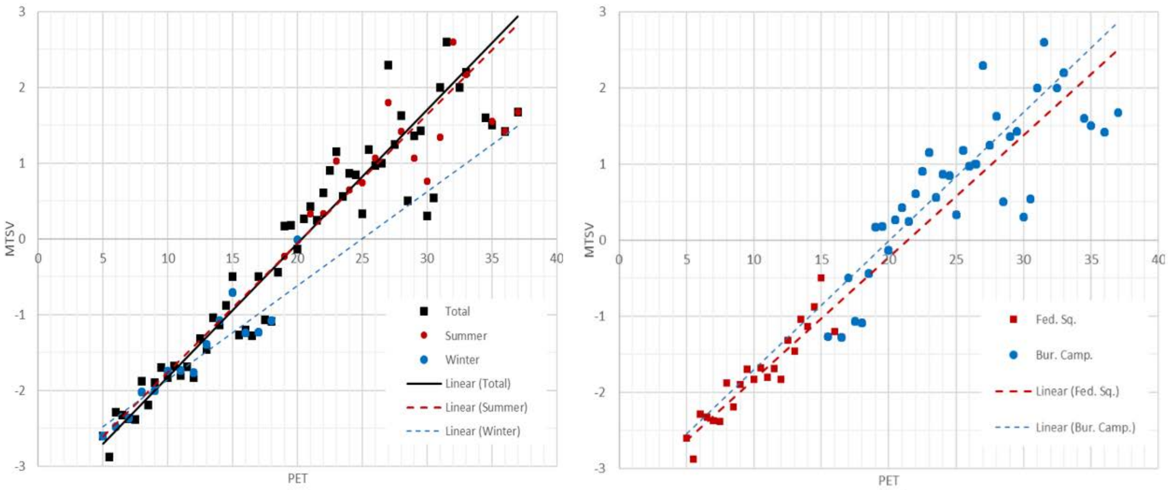
The NPET is retrieved from the linear regression (LR) between the mean thermal sensation votes (MTSV) and the thermal comfort index (PET) calculated from the measured micrometeorological data. Due to the significance of thermal adaptation, similar studies have determined the respondents' MTSVs for each temperature interval with different bins width of 0.5°C, 1°C, 1.2°C and 2°C PET (da Silveira Hirashima et al., 2016; Kántor et al., 2016; T.-P. Lin & Matzarakis, 2008; Salata et al., 2016; Shooshtarian & Ridley, 2017; Yang, Wong, & Zhang, 2013). This research determines the MTSV for each 0.5°C PET intervals for more precision as per the framework of Yang, Wong, and Zhang (2013). The fitted regression lines for the aggregated data, during summer, and winter are represented by Eqs. (2), (3), and (4) respectively (Fig. 7). The significant correlation revealed a powerful relationship between the two variables especially for the aggregated data having R^2 of 0.919.

$$MTSV = 0.176\ PET - 3.584 \qquad R^2 = 0.919,\ p < .001 \qquad \textbf{(2)}$$

$$MTSV = 0.169\ PET - 3.381 \qquad R^2 = 0.695,\ p < .001 \qquad \textbf{(3)}$$

$$MTSV = 0.127\ PET - 3.101 \qquad R^2 = 0.727,\ p < .001 \qquad \textbf{(4)}$$

By substituting MTSV=0 in Eq. (2), the value of the NPET was found to be 20.4°C. The values of NPET during summer and winter were calculated to be 20 and 24.4°C respectively. For Federation square and Burwood campus, their solved fitted equations attained NPETs of 19.9 and 20.7°C respectively. The higher NPET at Burwood campus indicates the higher tolerance of their users during both heat and cold conditions.



(a) **(b)**

Figure 7 Regression model between MTSV and PET for (a) the aggregated data, summer and winter (b) Federation square and Burwood campus.

4.2.2 Neutral PET range (NPETR)

The NPETR is the lowest benchmark reported in OTC studies. However, it allows a quick understanding of thermal comfort ranges within cities. The value of this benchmark is determined by solving the fitted LR equation with mean thermal sensation votes of ±0.5. NPETR values for the aggregated data in this study ranged from 17.5°C to 23.2°C. NPETR varied from 17°C to 22.9°C during summer and from 20°C to 28.4°C during winter.

4.2.3 Preferred PET (PPET)

Thermal preferences towards having cooler and warmer climatic conditions recorded by respondents were evaluated for considering bins with a width of 0.5°C PET. To calculate the PPET, a probit regression analysis for both warmer and cooler preferences was modelled and the intersection of both corresponded to the preferred temperature. This is the most commonly used method in PPET calculations that were originally recommended by Ballantyne, Hill, and Spencer (1977). Values of 19.2°C and 23.2°C were obtained for the aggregated data and during summer respectively from the two fitted lines as shown in Fig. 8. The non-parametric Chi-square assessing the goodness of fit of the probit models for both cooler and warmer preferences in the aggregated data indicated statistically significant results of (X^2 = 90.706, d(f) = 57, $p < 0.05$) and (X^2 = 103.643, d(f) = 57, $p < 0.01$) respectively. The probit models fitted well on both sides. The chi-square during winter indicated non-significant result, which indicates that winter data does not fit in the probit model.

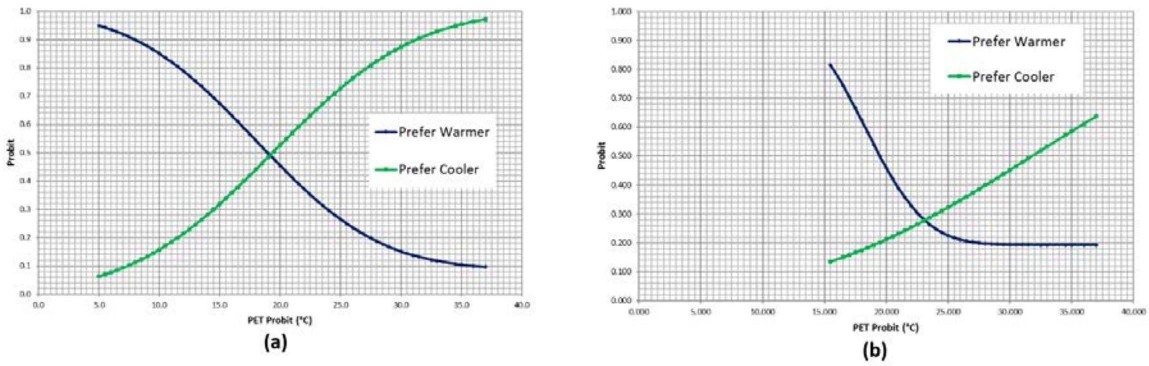


Figure 8 The preferred temperature obtained from the probit model for (a) all data (b) summer data

PPET for both urban places were also calculated using the logistic curve model with the probit function. Statistical significance of (X^2 = 60.490, d (f) = 39, $p < 0.005$) resulted for the different preferences in Federation square. In Burwood campus both warmer and cooler preferences also indicated statistical significance of (X^2 = 110.426, d (f) = 53, $p < 0.001$) and (X^2 = 96.322, d (f) = 53, $p < 0.001$) respectively. The preferred PET values obtained in Federation square and Burwood campus from the intersection of the two fitted probability lines are 19.3°C and 19.2°C which are 0.7 and 1.4°C less than the NPET obtained earlier.

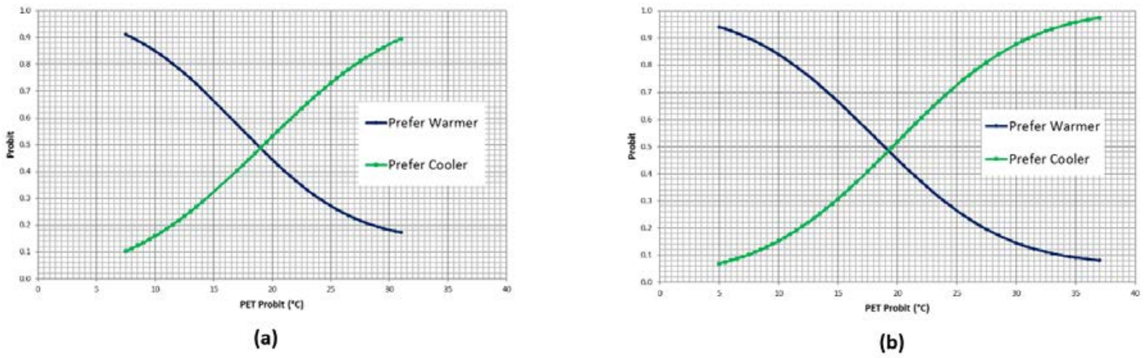


Figure 9 The preferred temperature obtained from the probit model for (a) Federation square (b) Burwood campus

4.2.4 Thermal acceptability range (TAR)

This benchmark is frequently determined in thermal comfort studies for the design of outdoor environments (Cheung & Jim, 2017). The common method of identifying TAR is the intersection of the acceptability line of 80 % or 90% with the quadratic polynomial fitting the acceptability percentages in 1°C or 2°C PET intervals. To calculate the TAR and the PET range for Melbourne, the best-fitted curve between the percentage of acceptability for in correspondence to PET bins with a width of 1°C were used (Fig. 10). The minimum acceptable rate for thermal conditions is 80% (ASHRAE, 2004); however, this percentage (20% unacceptability) showed a large range of acceptable temperature from 15 to 29.9°C. For more precision, a percentage of 90% acceptability range is selected for defining TAR, which was calculated to vary from 20 to 24.9°C. The TAR calculated at Federation square ranged from 17.5 to 22.6°C and in Burwood campus from 20.1 to 25.3°C with 90% and 88% acceptability rates respectively.

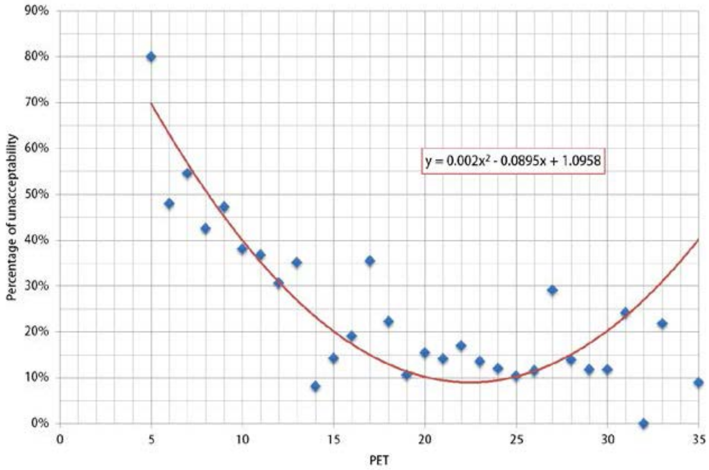


Figure 10 Distribution of Percentage of unacceptability votes

Due to the significance of TAR benchmark, this study also used the approach of Yang, Wong, and Jusuf (2013) relying on the assumption that the mean thermal sensation votes of ±0.85 on the ASHRAE scale correspond to 80% of thermal acceptability (ISO-7730, 2005). When substituting MTSV = ±0.85 in Eq. (2), a range of 15.5°C and 25.2°C is obtained. This range is narrower than its equivalent of 80% acceptability obtained from the quadratic polynomial model. The same pattern was found when calculating TAR for the different urban places as sown in Fig.11.

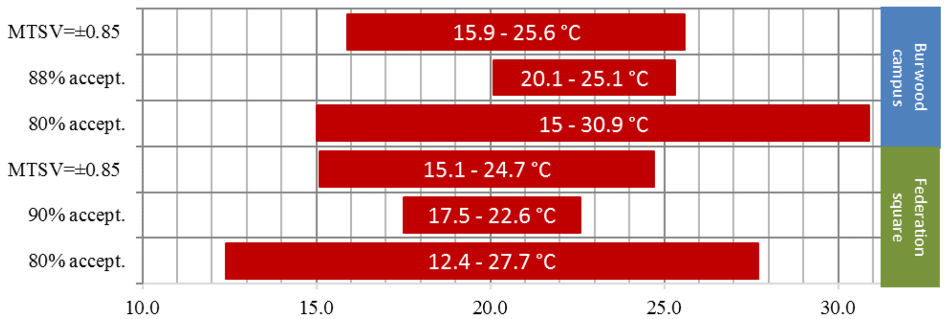
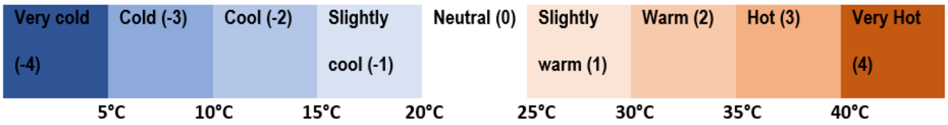


Figure 11 TAR using different methods in Federation square and Burwood campus

4.2.5 PET classification for Melbourne

To obtain the classification of thermal perception for Melbourne city, this study used the framework of Lin and Matzarakis (2008). The PET comfort classification is calculated by increasing and



decreasing the interval of each point in the scale by 5°C (the difference between 20 and 25°C previously calculated TAR). The PET classification results are shown in Fig. 12.

Figure 12 PET classification for Melbourne City, Australia.

5 Discussion

5.1 Thermal comfort benchmarks

5.1.1 Neutral PET (NPET)

Regional differences are noticed in the NPET values when comparing the obtained results to other studies. The NPET value was found to be 20.4°C, which is similar to Athens, Greece (Pantavou et al., 2013) classified with its hot dry summers. Although the context of this study is having the same climatic zone as Szeged, Hungary (Kántor et al., 2016), NPET is almost 2°C higher. This difference can be related to the lower mean temperature winter readings in Hungary when compared to those in Melbourne. A wide variation of almost 8°C is identified between NPET in this study and its equivalent in the tropical rainforest climate of Singapore (Yang, Wong, & Zhang, 2013).

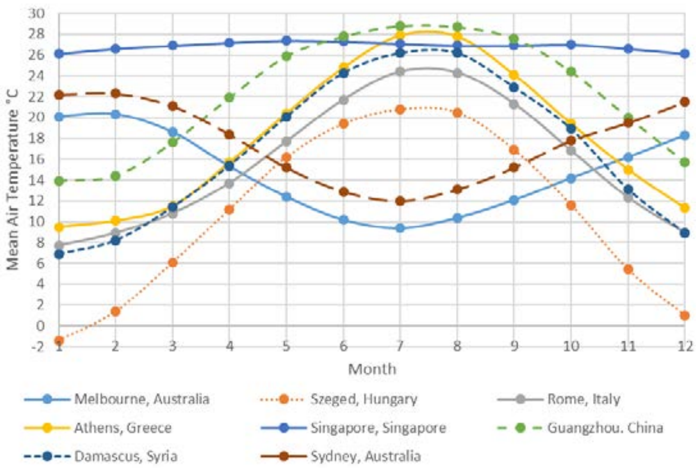


Figure 13 Mean air temperature in different OTC studies Source:(Climate-Data.org, 2017)

It is observed from Fig. 13 and Table 3 that the cities characterised by hot climates are having higher NPET than those having cold climates. Different NPET values in Guangzhou, China were calculated in different studies (Liu et al., 2016; Yang, Wong, & Zhang, 2013; Zhao et al., 2016); however, the different types of their studied urban places could explain this variation.

Another variation was detected during different seasons. NPET during summer was generally found to be higher than winter in the previous studies, with a difference varying from 0.9°C (Elnabawi et al., 2016) and 11.8°C (da Silveira Hirashima et al., 2016). In this study, NPET during winter was found to be 4.4°C higher than during summer. This variation was in line with other studies in Melbourne (Shooshtarian & Ridley, 2017) and Hungary (Kántor et al., 2016) having the same Cfb climatic classification that had higher values during autumn than summer of 4.63°C and 2.1°C respectively. Damascus (Yahia & Johansson, 2013) and Sydney (Spagnolo & de-Dear, 2003) also had the same pattern of higher NPET winter values of 7.6°C and 5.9°C respectively. In addition to the climate characteristics of the different regions, Li et al. (2016) and Salata et al. (2016) explained this variation by the psychological human mechanism of Alliesthesia, tending towards favouring high air temperature during cold and vice-versa.

Reference	Neutral PET				Comments and used analysis
	Summer	Winter	Other	Overall	
Melbourne, This study	20	24.4	-	20.4	Linear Regression(LR) MTSV vs PET bin (0.5°C)
Singapore, Singapore (Yang, Wong, & Zhang, 2013)				28.1	LR MTSV vs PET bin (0.5°C)
Singapore, Singapore (Yang, Wong, & Jusuf, 2013)				28.7	LR MTSV vs OT
Belo Horizonte, Brazil (da Silveira Hirashima et al., 2016)	27.7	15.9	-	-	LR MTSV vs PET bin (1°C)
Damascus, Syria (Yahia & Johansson, 2013)	15.8	23.4	-	-	PA using PET
Cairo, Egypt (Elnabawi et al., 2016)	29.5	24.3	-	-	LR between MTSV and PET)
Cairo, Egypt (Mahmoud, 2011)	27.4	26.5			Average LR MTSV vs PET for 9 zones

Guangzhou, China (Li et al., 2016)	-	15.6	25.6 spring	-	PET, (LR TSV vs PET)
Guangzhou, China (Zhao et al., 2016)	-	-	-	23.9	LR MTSV vs for each 2°C degree SET* interval
Changsha, China (Liu et al., 2016)	17.5	14.9	23.3 autumn	18.6	LR
Changsha, China (Yang, Wong, & Zhang, 2013)	-	-		27.9	LR MTSV vs PET bin (0.5°C)
Sydney, Australia (Spagnolo & de-Dear, 2003)	22.9	28.8		24	Probit intersection of trans. curves at 50% probability PET
Taiwan (Lin & Matzarakis, 2008)				27.2	LR MTSV vs PET bin (1°C)
Szeged, Hungary (Kántor, Égerházi, et al., 2012; Kántor, Unger, et al., 2012)				18.5 (LR)	LR and QR - MTSV vs PET bin (1°C)
Szeged, Hungary (Kántor et al., 2016)	16.4 (LR)		17.7 spring 18.5 autumn	18.53 (LR)	LR and QR - MTSV vs PET bin (1°C) and different interpretations for TSV = 0 in (PA)
Melbourne, Australia (Shooshtarian & Ridley, 2017)	20.47		19.4 spring 25.1 autumn		LR MTSV vs PET bin 2°C
Athens, Greece (Pantavou et al., 2013)				20.3	LR MTSV vs (index) bin (1°C)
Tel Aviv (Cohen et al., 2013)	23.9	22.7			LR MTSV vs (index) bin (1°C)
Rome, Italy (Salata et al., 2016)	26.9	24.9			LR mean TSV vs PET bin (1°C)
Taichung, Taiwan (Lin, 2009)	25.6	23.7			LR MTSV vs PET bin (1°C)

Table 3 Neutral PET values in different OTC studies

5.1.2 Neutral PET range (NPETR)

NPETR values for the aggregated data in this study ranged from 17.5°C to 23.2°C. This range is limited when compared to the corresponding range in Hungary (Kántor et al., 2016). Although both cities belong to the same climatic temperate zone, a wider range skewed toward cooler temperature is perceived in Hungary. This difference could also be explained by the lower mean temperature readings in Hungary in comparison to Melbourne city. On the other side, the values in Rome (Salata et al., 2016) were inclined towards higher temperature values, which again could be related to their higher mean temperature during summer as shown in Fig. 13.

NPETR varied from 17°C to 22.9°C during summer and from 20°C to 28.4°C during winter. Only the winter range can be compared to both Shanghai (Chen et al., 2015) and Changsha (Liu et al., 2016) that were found to have a skewness towards the lower temperature, which could also be related to their climatic characteristics. It is noticed that the winter range for Shanghai is wider due the diversity of climatic conditions during winter that makes residents more tolerant to the different climates as explained by Chen et al. (2015). These variations show that the different climatic conditions affect the users' thermal requirements.

City	Neutral PET Range			Comments and used analysis
	Summer	Winter	Overall	
Melbourne, This study	17 - 22.9	20 - 28.4	17.5 - 23.2	LR MTSV vs PET bin (0.5°C) TSV = ±0.5
Shanghai, China (Chen et al., 2015)		15 - 29		LR MTSV vs PET bin (1°C) TSV = ±0.5
Changsha, China (Liu et al., 2016)		15 - 22		LR MTSV vs PET bin (1°C) TSV = ±0.5
Szeged, Hungary (Kántor, Égerházi, et al., 2012; Kántor, Unger, et al., 2012)			7 - 39	LR MTSV vs PET bin (1°C) TSV = ±0.5
Szeged, Hungary (Kántor et al., 2016)			13.5 - 22.2	LR MTSV vs PET bin (1°C) TSV = ±0.5
Rome, Italy (Salata et al., 2016)			21.1 - 29.2	LR MTSV vs PET bin (1°C) TSV = ±0.5

Table 4 Neutral PET range values in different OTC studies

5.1.3 Preferred PET (PPET)

It is observed from the comparison in Table 5 that the PPET value for the aggregated data is almost similar to Szeged (Kántor et al., 2016) belonging to the same Cfb climatic zone. Other studies had very close PPET despite their different climate characteristics including Cairo (Elnabawi et al., 2016) and Guangzhou (Zhao et al., 2016), which belong to hot arid and humid subtropical climatic zones respectively. The same pattern is repeated for Singapore (Yang, Wong, & Zhang, 2013) and Sydney (Spagnolo & de-Dear, 2003) having tropical rainforest and humid subtropical climates respectively. The value of PET during summer (23.2°C) also resembles those calculated in Sydney (23.4°C), followed by Taichung (24.5°C), Melbourne (24.6 when using LR), and Rome (24.8°C). The difference between NPET and PPET for aggregated and summer data are -3.2 and 1.2°C respectively. Yang, Wong, and Jusuf (2013) explained this variance results from the respondents' preferences to the word 'cool' than 'warm' that have an undesirable psychological effect.

City	Neutral PET (°C)				Comments and used analysis
	Summer	Winter	Other	Overall	
Melbourne, this study	23.2			19.2	Probability analysis (PA) (1.2° difference from NPET)
Singapore, Singapore (Yang, Wong, & Zhang, 2013)				25.2	PA (2.9° difference)
Singapore, Singapore (Yang, Wong, & Jusuf, 2013)				26.5	PA (2.2° difference)
Belo Horizonte, Brazil (da Silveira Hirashima et al., 2016)	14.9	20.9			PA (12.8° (summer) and -5° (winter) difference)
Cairo, Egypt (Elnabawi et al., 2016)				24	PA (5.5° difference from NPET)
Guangzhou, China (Li et al., 2016)	-	18.8	30 spring	-	Polynomial relation MTSV & PET, (-4.4° (spring) -3.2°(winter) difference)
Guangzhou, China (Zhao et al., 2016)	-	-	-	23.7	PA (0.2° difference)
Changsha, China (Yang, Wong, & Zhang, 2013)	-	-		22.1	PA (5.8° difference)
Sydney, Australia (Spagnolo & de-Dear, 2003)	23.4	30.9		25	PA (-0.5 (summer), -2.1 (winter), -1° (total) difference)
Szeged, Hungary (Kántor et al., 2016)				18.53	PA with different interpretations for 'no change' votes (0.93°, -1.17°,& 1.03° difference)
Melbourne, Australia (Shooshtarian & Rajagopalan, 2017)	15 (PA) 24.6 (LR)		27.5spring, 32.1autumn		LR MTSV and PET and PA (5.4 (summer), -8.3 (spring), -7° (autumn) difference)
Rome, Italy (Salata et al., 2016)	24.8	22.5			PA (2.1° (summer) and 2.4° (winter) difference)
Taichung, Taiwan (Lin, 2009)	24.5	23			PA (1.1° (summer) and 0.7° (winter) difference)

Table 5 Preferred PET values in different OTC studies

5.1.4 Thermal acceptability range (TAR)

The values for TAR are compared with other studies as shown in Table 6. When comparing the results obtained from the 80% acceptability rate with peers, it was found that the other study in Melbourne (Shooshtarian & Rajagopalan, 2017) had a close range. However, their study had a wider range that might be explained by the nature of their studied place; a university campus having necessary activities tolerating less quality than other urban places where optional activities occur. Athens' study (Pantavou et al., 2013) also used 80% acceptability rate obtaining a range from 15.4 to 26°C, which indicate that their users are less tolerant to heat regardless their higher monthly mean temperature ranging from 10°C to 29°C. The range between 20°C and 24.9°C obtained from the 90% acceptability rate in this study could be also compared with the majority of other OTC studies using the same level. The variation between the different studies indicates that the climate characteristics are influencing the users' acceptability ranges (Li et al., 2016; Salata et al., 2016). The most noticeable aspect from the comparison is the narrower range in our study, which confirms that the users in Melbourne are exposed to limited and moderate climatic conditions. This is clear from its monthly mean temperature ranging from 9.75 to 20.2°C. A wider range of TAR was found in Guangzhou (Li et al., 2016) ranging from 18.1 to 31.1°C due to having mean temperature values ranging from 13 and 29°C. Similar values were found in Cairo (Elnabawi et al., 2016) and Changsha (Yang, Wong, & Zhang, 2013). Both cities do not belong to the same climatic zones, however, they have similar monthly mean temperature of 14- 28°C and 16-30°C for Cairo and Changsha respectively. Yang, Wong, and Jusuf (2013) was the only study using MSTV=±0.85 for calculating TAR. Their calculated TAR was about 4 to 5°C higher than Melbourne, which can also be related to their climatic characteristics.

City	TAR (°C)		Comments and used analysis
	From	To	
Melbourne , this study	15 20 15.5	29.9 (80%) 24.9 (90%) 25.2 (±0.85)	90% and 80% acceptability rate, and MTSV = ±0.85
Singapore, Singapore (Yang, Wong, & Zhang, 2013)	24	30	88% acceptability rate
Singapore, Singapore (Yang, Wong, & Jusuf, 2013)	26.3	31.7	MTSV = ±0.85
Belo Horizonte, Brazil (da Silveira Hirashima et al., 2016)	19	27	Predicted probability model
Damascus, Syria (Yahia & Johansson, 2013)	22.8 21	28.5 (90%) 31.3 (80%)	90% and 80% acceptability rate
Cairo, Egypt (Elnabawi et al., 2016)	23	32	90% acceptability rate
Shanghai, China (Chen et al., 2015)	13 9	30 autumn 25 winter	90% acceptability rate
Guangzhou, China (Li et al., 2016)	18.1 16.9 27.9	31.1 22.7 winter 32.3 spring ≤32.4 summer	90% acceptability rate
Guangzhou, China (Zhao et al., 2016)	28.54 (90%)	31.1 (80%)	90% and 80% acceptability rate

Changsha, China (Yang, Wong, & Zhang, 2013)	24	31	88% acceptability rate
Sun moon lake, Taiwan (Lin & Matzarakis, 2008)	21.6	35.6	88% acceptability rate
Melbourne, Australia (Shooshtarian & Rajagopalan, 2017)	14.2 19.8 (TSV)	33.1 24.1 (TSV)	80% acceptability rate from direct thermal acceptance and from TSV
Athens, Greece (Pantavou et al., 2013)	15.4	26.5	80% acceptability rate
Tel Aviv (Cohen et al., 2013)	19 20	25 winter 26 summer	90% acceptability rate
Taichung, Taiwan (Lin, 2009)	21.3	28.5	90% acceptability rate

Table 6 Thermal Acceptability Range values in different OTC studies

5.1.5 PET classification for Melbourne

PET classification for Melbourne city in comparison to other studies is illustrated in Table 7. The table shows that the values of temperature sensation scale for Melbourne are very close to Western/Middle Europe. However, Melbourne residents are slightly less tolerated to cold temperature as the cold votes lied between 5 and 10°C while the same votes for Western/Middle Europe region ranged from 4°C to 8°C. A great difference can also be observed between the scales in Taiwan, which might be related to their mean monthly temperature ranging from 16 to 29°C. Taiwan classification showed lower tolerance to cold and vice versa for warm climatic conditions. The comparison could be explained by the mean monthly temperature for the different regions, however, some limitation could be perceived due to the variety of methods used in identifying the PET classification. The method used in this study is similar to its equivalent in Taiwan (Lin & Matzarakis, 2008). However, Tel Aviv (Cohen et al., 2013), Tianjin (Lai et al., 2014) and Melbourne (Shooshtarian & Rajagopalan, 2017) used discriminant analysis, linear regression and probit analysis respectively. Yang, Wong, and Zhang (2013) used the 88% in identifying the neutral range, which is very close to the 90% used in this study. However, they used the same intervals of 4°C used by Lin and Matzarakis (2008) rather than the difference calculated from TAR.

	PET (°C) range calculated for								
	Melbourne, this study	Western /Middle Europe (Matzarakis et al., 1999)	Tel Aviv (Cohen et al., 2013)	Taiwan (Lin & Matzarakis, 2008)	Tianjin (Lai et al., 2014)	Changsha (Liu et al., 2016)	Changsha (Yang, Wong, & Zhang, 2013)	Singapore (Yang, Wong, & Zhang, 2013)	Melbourne (Shooshtarian & Rajagopalan, 2017)
Very Cold (-4)	5	4	8	14	-16	-8	NA	NA	NA
Cold (-3)	10	8	12	18	-11	-1	NA	NA	9.4
Cool (-2)	15	13	15	22	-6	7	20	20	13.2
Slightly Cool (-1)	20	18	19	26	11	15	24	24	19.4
Neutral (0)	25	23	26	30	24	22	31	30	22.9
Slightly Warm (1)	30	29	28	34	31	30	35	34	29.2
Warm (2)	35	35	34	38	36	38	39	38	45
Hot (3)	40	41	40	42	46	46	43	42	NA
Very Hot (4)									

Table 7 classification in different OTC studies

6 Conclusion

Outdoor places have a significant role in the liveability and sustainability within cities. Outdoor thermal comfort benchmarks could support the design of comfortable outdoor places as well as reducing the cooling energy demand for indoor settings. This paper aimed to identify these OTC benchmarks for the Australian Temperate Oceanic climatic zone. Various methods were used in identifying the different benchmarks, which obstruct having reasonable comparisons between the different regions (Cheung & Jim, 2017; Salata et al., 2016). Accordingly, the study reviewed the commonly used methods to obtain the different benchmarks. To analyse objective measurements and subjective assessments, meteorological measurements were monitored during summer and winter simultaneously with 2123 randomly distributed questionnaires covering personal data, thermal perception, preference, and acceptance. NPET were calculated using a linear regression between the mean thermal sensation votes (MTSV) for each temperature interval of PET calculated based on measured micrometeorological data. When substituting MTSV=0 in the regression, NPET was found to be 20.4°C. NPET values in Federation square and Burwood campus were of 19.9°C and 20.7°C respectively suggesting that the campus' users have higher tolerance towards both heat and cold conditions. This could return to the necessary activities realised in the campus, where less quality of physical characteristics could be acceptable (Gehl, 2011). NPET was calculated to be also higher than its equivalent in summer. These seasonal variations were explained by the psychological human mechanism of Alliesthesia, tending towards favouring high air temperature during cold and vice-versa (Li et al., 2016; Salata et al., 2016). By solving the equation having MTSV=±0.5, the calculated NPETR varied from 17.5°C to 23.2°C. PPET is typically obtained from the intersection of the two probit analysis for cooler and warmer preferences recorded by users. PPET values for the aggregated and summer data were calculated to be 19.2°C and 23.2°C respectively. Due to its significance, TAR was obtained using three different methods. The main used method was the intersected acceptability line of 90% with the quadratic polynomial fitting the acceptability percentages in 1°C PET intervals. A thermal acceptability rate ranging from 20 and 24.9°C was attained using this method. Although NPET and PPET were not in the centre of the acceptability range, Cheung and Jim (2017) explained that by the users' physical, psychological, and physiological status influencing their preferences. The PET classifications were found to range from very cold (≤5°C), cold (5°C-10°C), cool (10°C-15°C), slightly cool (15°C-20°C), neutral (20°C-25°C), slightly warm (25°C-30°C), warm (30°C-35°C), hot (35°C-40°C) and very hot (≥40°C). The influence of climatic conditions, represented by the mean monthly temperature, and the thermal adaptation, were two main reasons for the variations of results in the different OTC studies. Users residing in hot and humid regions showed higher tolerance toward high temperature when compared to those in temperate climatic conditions. Finally, these benchmarks provide a good representation for OTC in the temperate oceanic climatic zones in Australia represented by two studied urban places in Melbourne city. The same method could also be employed internationally to obtain equivalents benchmarks in the different regions.

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